

Measuring Electrostatic Phenomena on Mars and the Moon

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Abstract—Telescopic observations of Mars and the moon date from 1610, when Galileo turned his first telescope to the heavens. It was not until spacecraft began to orbit and eventually land on these two bodies that a more accurate understanding was obtained. NASA's Apollo program to the moon brought twelve astronauts to its surface and returned lunar samples to earth for detailed studies. This paper will summarize our current understanding of the electrostatic properties of the martian and lunar regoliths. Ground based laboratory experiments to understand the electrostatic properties of these regoliths as well as those of the martian atmosphere will be summarized. The design and construction of a flight instrument to measure the electrostatic response of several polymers when exposed to martian soil and dust will be presented.

I. INTRODUCTION

Telescopic observations of Mars date from 1610, when Galileo turned his first telescope to the heavens. At the end of the nineteenth century, Flammarion summarized what had been learned until then in an encyclopedic work. It was not until spacecraft began to orbit and eventually land on the fourth planet that a more accurate understanding of Mars was obtained.

Although only twelve humans have stood on the surface of the moon, planetary scientists have a good understanding of its physical properties. Moon samples brought back by the Apollo astronauts have allowed scientists to study many of its properties at leisure.

Mars has a rotation period of 24 h, 37 min 22 s, almost equal to the earth's and its axis is tilted at an angle of 23.19°, also nearly identical to the earth's 23.45° providing the planet with seasonal changes that can be seen from earth even through a small telescope. Mars, however, has a mass of only one tenth that of earth's and half earth's diameter.

The moon is so large compared to its primary planet, that the earth-moon system can be classified as a double planet. Table 1 lists some physical

properties of Mars and the moon. Table 2 lists some properties of the martian and lunar atmospheres.

Table 1. Physical Properties of Mars and the Moon

	Mars	Moon
Orbit Inclinat.	23° 19'	6° 41'
Orbital Period	24 h 37 min	27.3 d
Diameter	6796 km	3476 km
Mass	0.64×10^{24} kg	7.35×10^{22} kg
Density	3.94 g/cm ³	3.36 g/cm ³
Surface gravity	0.379 g	0.167 g
Surface temp.	-140° to 20°C	-170° to 130°C

Table 2. Atmospheric Properties of Mars and the Moon

	Mars		Moon	
Surface pressure (mbar)	5 to 10		1×10^{-12}	
Composition	Gas	%	Gas	%
	CO ₂	95	Ar	79.2
	N ₂	2.7	He	19.8
	Ar	1.6	O	1
	O ₂	0.15	Na	Trace
	H ₂ O	0.03	H	Trace

II. ELECTROSTATIC PROPERTIES OF MARS AND THE MOON

Most of what is known about the electrical properties of the Martian surface has been obtained with Earth-based radar measurements [Tyler *et al.*, 1976], microwave radiometry [Kuz'min and Losovskii, 1984], and radio occultation of Mars orbiting spacecraft [Simpson and Tyler, 1984]. These measurements were consistent with the electrical properties of lunar rocks and of frozen terrestrial silicates [Olhoeft, 1990]. G.R. Olhoeft at the U.S. Geological Survey speculates that since these materials have low electrical conductivities, radio waves will penetrate the Martian and Lunar soil for large distances. In addition, Martian dust and sand particles may acquire high electrostatic charges and exhibit high photoconduction effects, as measured in lunar samples [Olhoeft 1981].

Stationary surface sand and dust on Mars may be electrostatically charged due to incident UV radiation reaching the surface. Although the total integrated UV flux over 200-400 nm is comparable to Earth's, shorter wavelengths contribute a larger proportion of this flux [Catling and Cockell, 2000]. Contact charging may also occur due to collisions between wind-blown dust particles and stationary surface particulate matter. Planet-wide dust storms on Mars have been observed to last for several months (Fig 1). Wind velocities up to 32 m/s have been measured during these dust storms (Gaier, *et al.*, 1990). Dust devils (small, localized dust storms) up to 10 km high were detected during the 1997 Mars Pathfinder mission with daily frequency.



Figure 1. Global dust storm on Mars

There are no winds in the tenuous lunar atmosphere. However, there has been speculation

of dust transport taking place on the moon. The issue of dust levitation and transport of lunar dust has been controversial since it was first raised during the Apollo missions [Gold and Williams, 1973]. A horizon glow was reported by Apollo astronauts [Zook and McCoy, 1991] (Fig. 2). This glow has been interpreted as evidence of transient dust clouds above the lunar surface. Observations with the lunar Surveyor spacecraft [Rennison and Criswell, 1973] and the Lunar Ejecta and Meteorites Experiment (LEAM) on Apollo 17 indicated the presence of dust clouds [Berg *et al.*, 1975]. Although no theoretical model satisfactorily explains the phenomenon, it has been suggested that electrostatic charging of the lunar surface due to exposure to charged particles from the solar wind as well as UV radiation could result in the levitation and transport of dust particles [Horanyi, 1998].

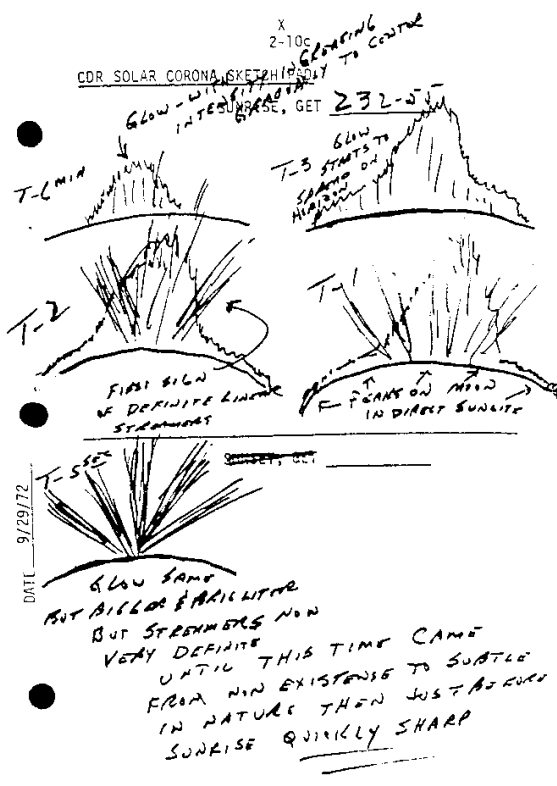


Figure 2. Apollo astronauts sketches from orbit showing streamers reaching up to 100 km from the surface.

A. *In situ* Electrostatics Experiments

Only one experiment with indirect electrostatics measurements has been flown on a landing mission to Mars. The Wheel Abrasion Experiment (WAE) on the Mars Pathfinder rover (Fig. 3) was designed to measure the abrasiveness of the martian dust as well as its adhesiveness [Ferguson *et al*, 1999]. Fifteen thin film insulator and metal samples mounted on the wheel specularly reflected sunlight to a photovoltaic sensor. During the mission, lander camera images showed dust accumulating on the rover wheels as the vehicle moved. WAE experiments showed a decrease in the reflectance signals. This decrease was interpreted as being due to dust adhering to the film samples.

The tentative conclusion from WAE experiments is that the surface dust may have acquired an electrostatic charge as the rover wheels rolled on the planet's surface, causing the dust particles to adhere to the film surfaces.

An experiment to determine the electrical properties of the surface of the moon was flown on Apollo 17. The Surface Electrical Properties experiment (SEP) was used to explore subsurface materials at the Apollo 17 landing site using electromagnetic radiation (Fig 2) [Berg, 1973]. The purpose of the surface electrical properties experiment was to obtain data about the electromagnetic energy transmission, absorption, and reflection characteristics of the lunar surface and subsurface for use in the development of a geological model of the upper layers of the moon. This experiment determined layering, searched for pressure of water below the surface, and measured electrical properties *in situ*, determining these as a function of depth. Any moisture present was easily detected because minute amounts of water in rocks or subsoil change the electrical conductivity by several orders of magnitude. The equipment for this experiment consisted of a deployable self-contained transmitter, a multiple frequency transmitter antenna, a portable receiver/recorder on the Lunar Rover, a wide-bandwidth mutually orthogonal receiver antenna, and a retrievable data recording device. Wheel turns were counted for distance, and azimuth was recorded using the navigation system. The recorder was then returned to earth.



Figure 3. Mars Pathfinder Rover

SEP determined the relative dielectric constant of the lunar soil at frequencies of 1 to 32 MHz to be approximately 3 to 4 near the surface and 6 to 7 at about 50 m below the surface. The experiment determined that no liquid water was present in the outer 1 to 2 km.

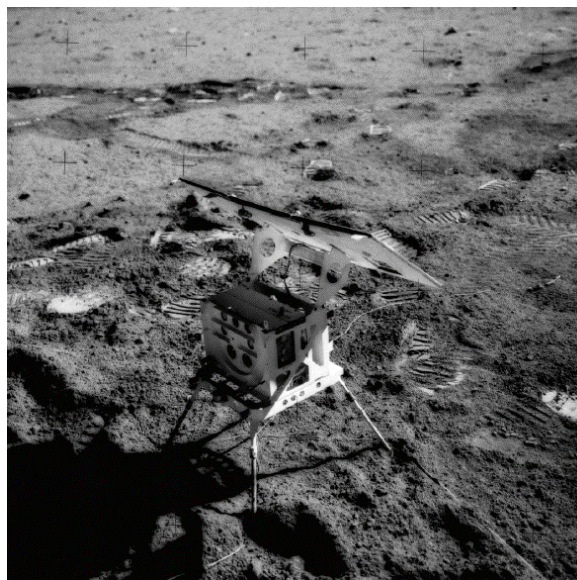


Figure 4. The Surface Electrical Properties Experiment flown to the Moon on Apollo 17.

B. Ground Experiments

Several ground experiments in simulated martian environments have been performed. These experiments attempt to characterize the electrostatic properties of martian and lunar soil simulants as well as to study the charge exchange between simulant particles and polymer surfaces.

1. Early Experiments

In 1973, laboratory experiments in a martian-like atmosphere showed that a dust grain can charge to as high as 10^4 e⁻ [Eden and Vonnegut, 1973]. Filamentary and glow discharges were observed. Several years later, laboratory experiments in a dusty, turbulent martian environment suggested that 5 kV/m electric fields could be produced (Sentman, 1991).

2. Preflight Experiments

Discoveries such as the ones mentioned prompted NASA researchers to consider the possibility of electrical discharges affecting the Mars Pathfinder mission. Experiments with a model of the Pathfinder rover wheel under conditions simulating the surface environment on Mars showed that, at typical rover speeds, charge would accumulate on the wheel producing electrical potential differences of the order of 100 V [Siebert and Kolecki, 1996]. These potential differences are believed sufficient to generate electrical discharges in the martian atmosphere with average arc time intervals of the order of 1 μ s. Currents of about 10 mA could be produced which would interfere with electrical equipment of the rover. To mitigate this possible problem, discharge points were added to the Pathfinder rover antenna base (Fig. 5).

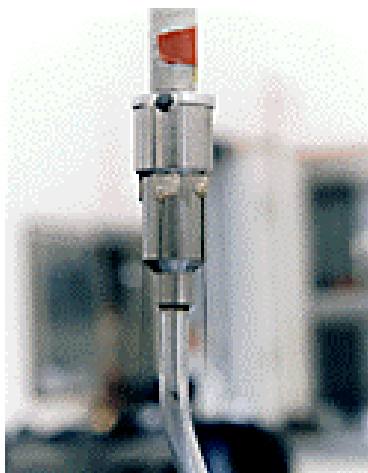


Figure 5. Discharge points on the antenna of the Mars Pathfinder Rover

3. Martian Soil Simulant Sliding Experiment

Recent experiments to simulate the electrostatic effects of airborne particles moving across the surfaces of materials that may be used in solar panels, camera lenses, and other instrumentation have been performed [Calle *et al*, 2001]. A martian regolith granular material prepared from Hawaiian volcanic ash to simulate the martian soil [Allen *et al*, 1998] was placed in a metal container able to swing back and forth around a pivot point. An array of five electrometer sensors capped with different insulating polymers commonly used in space applications was placed at the bottom of this container (Fig. 6). The entire assembly was placed in the Mars Electrostatics Chamber (MEC) in a CO₂ atmosphere at 10 mbar of pressure. Simulant particles rolling back and forth over the five insulators generated charges of the order of 20 pC on the 6 mm diameter polymers. Charge transfer mainly occurred with larger, 200 to 400 μ m grains sliding over the surfaces. Smaller dust particles, less than 5 μ m in diameter, remained electrostatically attached to the polymer surfaces. Overall electrostatic potentials were reduced when these smaller particles remained on the surfaces due to the proximity of the exchanged charges between these particles and the surfaces.

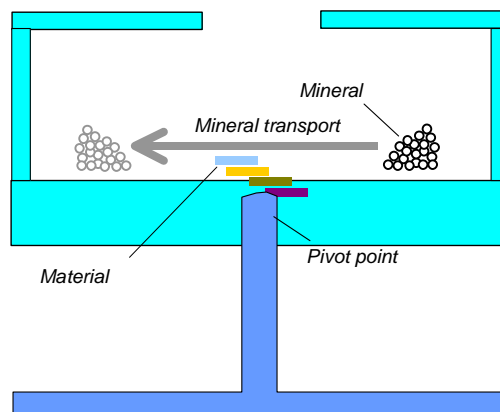


Figure 6. Diagram of the rocking chamber. Martian and Lunar simulant particles slide across the 5 insulating surfaces capping electrometer sensors

4. Deflection Board Experiment

A second type of sliding contact experiment with martian simulant particles was performed under similar simulated martian environmental conditions [Gross, 2001]. In this experiment, 1 gram of martian simulant particles ranging in size from about 5 to 300 μm were dropped onto several metallic and non metallic boards placed at a 45° angle in a vacuum chamber at 10 mbars. Triboelectric charging of the particles occurred as particles of different sizes rubbed against each other and with the container. This charge was measured in a Faraday cup to be of the order of 225 pC. Charges measured on the simulant sample after sliding on the samples are shown in Fig. 7.

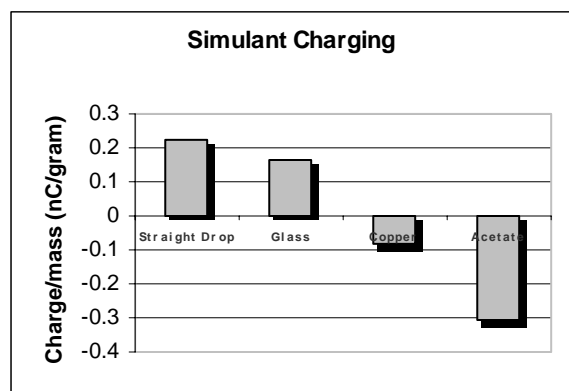


Figure 7. Charge to mass ratios for simulant charging in the deflection board experiment [Gross 2001].

5. Wind Simulation Experiments

Results from the Viking and Pathfinder missions to Mars show that Martian dust is less than a few micrometers in diameter [Tomasko *et al*, 1999; Greely *et al*, 1999; Metzger *et al*, 1999]. Although the mechanism for dust loading into the atmosphere is not well known, both Viking and Pathfinder observed considerable airborne dust [Hanson, 1997]. Winds, which on Mars can reach speeds of 32 m/s, transport these particles over long distances. Triboelectric charge can be generated between colliding particles in this fairly chaotic environment. Charged and uncharged particles moving in these dust storms will charge the surfaces of landing spacecraft and their equipment, producing unwanted potentials. The fundamental

understanding of this interaction is still an unresolved problem in physics [Kadanoff, 1999; Aranson, 2000]. Experiments to characterize this interaction are a first step in the development of a more complete understanding of this phenomenon.

Experiments to quantify this phenomenon have been performed in our laboratory using two different approaches. In the first approach, the KSC Dust Impeller, a device to propel submillimeter-size particles without contact at speeds up to 20 m/s at low pressures, was used for these experiments [Calle *et al*, 2001c]. Mars simulant particles, 5 μm in diameter, were baked at 150 °C for at least 24 hours to remove moisture before being placed in a vacuum chamber at 5 mbars. Winds with speeds of 20 m/s were generated in the chamber with the Dust Impeller. Dry simulant particles having a total mass of about 1 gram were propelled by the moving CO₂ molecules to several polymer samples 6 mm in diameter, each backed by an electrometer sensor. Charges ranging from -5 pC for Teflon to 19 pC for Fiberglass were measured.

In a second approach to quantify the electrostatic response of materials exposed to wind blown particles, fluidized 5 μm -diameter martian simulant particles were propelled with compressed dry air toward each one of the 6-mm diameter polymers backed by an electrometer at speeds of 30 m/s within a closed chamber at 5% relative humidity. Since the average vertical flux vortices near Mars Pathfinder during a dust devil event was 0.5 g/m²/s [Metzger, 2001], the flow rate was adjusted to deliver 1 g/m²/s. The particles travel through a grounded metal tube 3.9 mm in diameter. The average charge to mass ratio of the simulant as it came out of the tube was measured to be 2.8 $\mu\text{C/g}$.

6. Electrostatic Charging of Lunar Dust

Experiments to investigate the levitation of lunar dust particles by electrostatic charging of the particles with UV radiation and solar wind plasma are currently underway. An experiment investigate the charging of individual lunar simulant dust particles from photoemission and from electron collection within a UV-induced

photoelectron sheath has recently been conducted [Sichafoose *et al*, 2000]. Secondary electron production from these particles in the energy range of $20 \leq E \leq 90$ eV of the bombarding electrons are similar to those measured by Apollo 17. The experiment showed that multiple charge states can exist on the moon which are caused by the plasma tail of the earth [Horanyi, 1998].

7. Environmental Simulators

In addition to flight instrumentation, the evaluation, validation, and testing of flight instrumentation requires planetary environmental simulators. Simulators include atmospheric simulators and wind simulators.

a. MARSWIT

The Martian Surface Wind Tunnel (MARSWIT) at NASA Ames Research Center, located in a vacuum test chamber, was put into operation in 1976. It is a 13 m open-circuit boundary-layer wind tunnel that operates at atmospheric pressures of 3.0 mb to 1 bar, using carbon dioxide, air, or nitrogen. It is used to study the physics of windblown grains in the martian environment, including assessment of minimum wind speeds to set particles into motion on Mars. Wind velocities can be varied from 0 to 12 m/s at 1 bar and up to 150 m/s at 3 mb pressure.

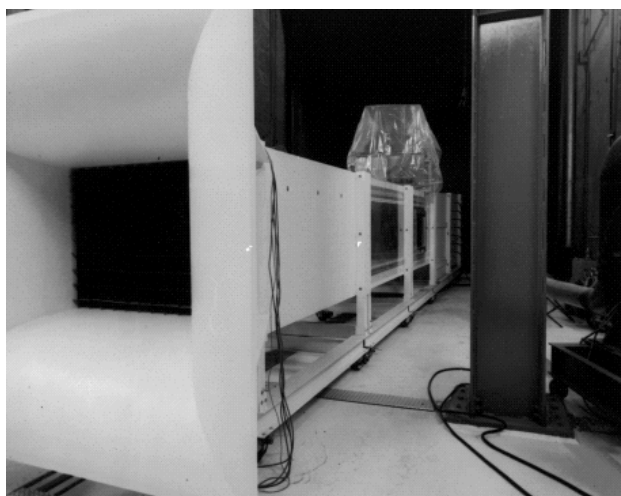


Figure 8. Mars Surface Wind Tunnel (MARSWIT) at NASA Ames Research Center.

b. Mars Electrostatics Chamber

The Kennedy Space Center Mars Electrostatics Chamber (MEC), a cylindrical vacuum chamber with a volume of 1.5 m^3 , was designed to simulate limited martian environmental conditions for electrostatics studies as well as for other areas of research (figure 5) [Calle, 2001b]. The MEC has been outfitted with an automated control system and a graphical user interface. The automation system consists of four subsystems: pressure control, temperature control, atmosphere control, and pneumatic control. The pressure and temperature control subsystems bring the chamber to 10 mbar and -90° C . The atmosphere control subsystem maintains a 100% carbon dioxide atmosphere at 10 mbar in the chamber. The pneumatic control system supplies compressed air to the pneumatic valves in the system. The MEC has a $1.43 \text{ m} \times 0.80 \text{ m}$ experiment deck, a vacuum depressurization time of 20 min, controlled repressurization time of 10 minutes, and can be repressurized in an emergency in 10 min.



Figure 9. The Mars Electrostatics Chamber (MEC) at NASA Kennedy Space Center.

8. Theoretical Models

A model proposing the electrification of Martian dust storms based on the effective electrical charging of a dust grain has been proposed

[Farrel *et al*, 1999]. Assuming that electrification of dust grains is easier in the low atmospheric pressure of Mars, as shown in the laboratory [Eden and Vonnegut, 1973], calculations give a maximum charge density of 10^6 e/cm³ for a μ m-sized dust particle. It is further assumed that triboelectrification and inductive processes are the charging mechanisms for these particles. Farrell *et al* show that the martian atmosphere cannot sustain a large group of charges at the maximum charge density. An electrically active dust cloud 10 km in diameter made of a collection of a large number of these particles would have an electric field moment of about 2.5 kC m. This value would give a limiting charge density of approximately 200 e/cm³.

The model predicts that extremely large DC electric fields may not occur on Mars, with corona discharge providing the limiting effect. A global electric circuit such as the one existing on earth probably does not exist, with local isolated pockets of electrical activity taking place instead.

The local electrical storms may become coupled, with two neighboring storms generating a large repulsive electric field. It is suggested that large vertical fields such as these could provide the mechanism for dust loading into the atmosphere.

III. DESIGN OF A FLIGHT INSTRUMENT

Flight instrumentation for an exploration mission to Mars requires a demonstrated capability of survival in the stern interplanetary space environment while in transit and the capability to function in the Martian environment once on the planet. Science payloads must also be able to withstand the accelerations and vibration during launch of the spacecraft that carries it. Table 3 lists these environmental requirements.

The conditions outlined in Table 3 generally exceed the rated tolerances of commercially available electronic components. Instrument components must be tested to assure operation and survival during the mission. Payload testing is a crucial component of flight instrumentation development. During mission operation, heaters, radiation and electrostatic shields, and other protection devices

might be available to bring instrumentation to within the required tolerances for the specific science payload.

Table 3. Mission Environment
[from Buehler *et al*, 2000].

Location	Parameter	Value
Earth	Planetary Protect. (H ₂ O ₂)	55°C
Launch	Launch Acceleration	3000 g
Cruise	Radiation Dose	1500 rad/yr
Mars	Radiation Dose	10 rad/yr
Mars	Temp Operate	-40 to 30°C
Mars	Temp Survival	-107 to 20°C
Mars	Temp Variation	60°C/day
Mars	Pressure	5-10 mb [2]
Mars	Atmosphere	CO ₂ 95%
Mars	Humidity	<0.1 % [2]

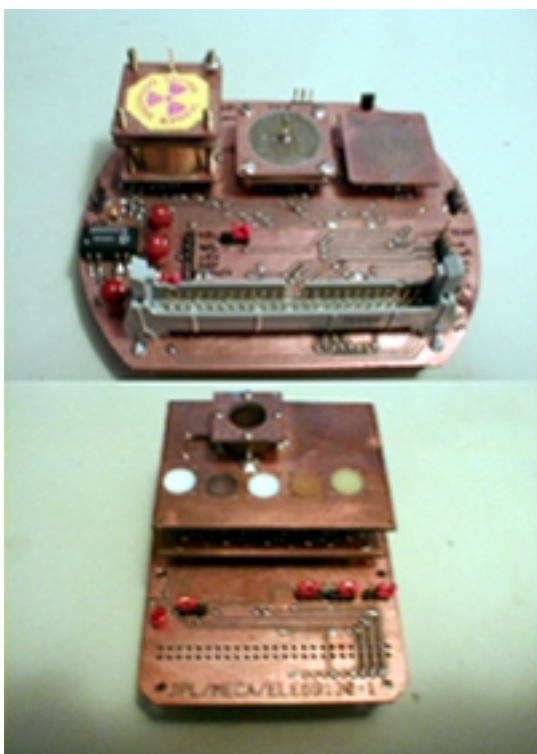
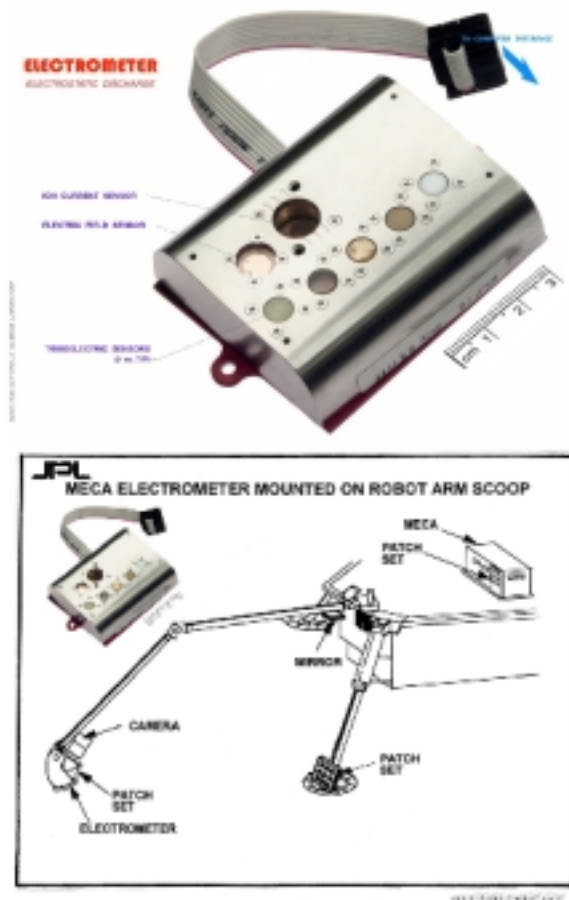
The Mars Environmental Capability Assessment (MECA) electrometer, an instrument to measure the triboelectric charge developed on 5 insulators was designed and built for the Marie Curie lander on the Mars Global Surveyor 2001 mission. The recent realignment of NASA's Mars exploration program changed the objectives of this mission, transforming it into the Mars Odyssey mission, which launched from the Kennedy Space Center on April 7, 2001 without a lander. The flight instrument developed on a collaboration between NASA's Jet Propulsion Laboratory and NASA Kennedy Space Center became the parent technology for many of our future exploration instruments.

In addition to the five triboelectric sensors, the MECA electrometer also contains an electric field sensor to measure the atmospheric electric field strength near the surface, an ion gauge to measure atmospheric ions, as well as a thermometer. The parameters for the triboelectric and electric field sensors as well as for the ion gauge are listed in Table 4. These requirements were achieved by using high resistance printed wiring boards, guard rings, one op-amp per sensor, and rigorous board cleaning.

Table 4. MECA Electrometer Performance Parameters [from Mantovani *et al*, 2001]

Parameter		
Tribo Voltage Sensitivity	1.8 kV/V	0.25 nC/V
Tribo Voltage Range	± 7.2 kV	± 1 nC
Tribo Voltage Resolution	3.5 V	0.5 pC
Ion Current Sensitivity	30 pA/V	
Ion Current Range	± 120 pA	
Ion Current Resolution	60 fA	

The MECA Electrometer was developed in several different stages (Fig. 10). Two prototypes were constructed to verify the performance of the electronics and to develop the form factor for the flight instrument. The flight version (of which eight units were fabricated) is shown in figure 11. This version uses a titanium case in a volume of ~ 50 cm³, total mass of ~ 50 g, and power consumption of < 250 mW. The insulator selection for the triboelectric sensors is shown in Table 5.

**Figure 10.** The two prototypes of the MECA Electrometer: ELE1 through ELE4 on the left, and ELE5-ELE7 on the right.**Figure 11.** (Top) Flight version of the MECA Electrometer with a titanium case, five triboelectric sensors with insulating materials, an ion gauge, and a thermometer. (Bottom) Electrometer and robot arm configuration.**Table 5.** Triboelectric Sensor Dielectrics [from Buehler *et al*, “2000].

No.	Material Name	Dielec. Constant 1 MHz	Bulk Resistivity (ohm-cm)
TRI1	G10, FR4	4.7 [4]	7.8E15 [4]
TRI2	Lexan™	2.96 [6]	2E16 [6]
TRI3	Teflon™, PTFE	2.1 [7]	1E18 [5]
TRI4	Rulon J™	2.4 [8]	8.2E18 [8]
TRI5	Lucite™, PMMA	2.63 [7]	>5E16 [6] >1E14 [9]

Development of instrumentation for future planetary missions based on the MECA electrometer is currently under way at Kennedy

Space Center as well as at the Jet Propulsion Laboratory.

IV. CONCLUSIONS

A great deal of progress in the understanding of electrostatic phenomena on Mars and the moon has taken place during the last 30 years. Most of what has been learned comes from ground-based experiments. No experiment designed solely to measure this phenomenon on Mars or the moon has ever flown although a few indirect experiments have been performed.

The planned Mars exploration missions present great opportunities for *in situ* electrostatics experiments. Although no missions to the moon are currently being planned, the possibility exists for a manned lunar mission as a try out for a human voyage to Mars.

ACKNOWLEDGEMENTS

Martin G. Buehler at the Jet Propulsion Laboratory, in close collaboration with our laboratory, designed and developed the MECA electrometer. James G. Mantovani at the Florida Institute of Technology has made significant contributions to all of the NASA Kennedy Space Center experiments presented here. Charles R. Buehler at Swales Aerospace contributed extensively to many of these experiments. The work done by Ellen E. Groop and Michael D. Hogue of NASA KSC and Andrew Nowicki of Dynacs on most of the KSC experiments is also acknowledged here. Randy Buchanan of Mississippi State University is responsible for the automation of the Mars Electrostatics Chamber at KSC.

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